AN EMPIRICAL STUDY ON THE CLOSE-RANGE POST-RICOCHET ORIENTATION OF AK BULLETS (7.62 MM × 39 MM)

1. Introduction

The destabilisation of bullets after ricochet is a well-known phenomenon that has been empirically tested and reported in many studies. Bullets can destabilise and tumble when they start their secondary flights after ricocheting off surfaces. Destabilisation occurs due to the changing orientation of a spinning projectile's axis after impacting a surface at low incident angles [1]. This phenomenon has a great forensic significance when identifying gunshot injuries caused by ricocheting bullets [2] and identifying the distance from which severe or fatal wounds could be inflicted by ricocheting bullets [3].

An exploration into the existing forensic-related literature highlights that most of the injuries and deaths of bullet ricochet incidents are due to the bullets ricocheting close to the victims [4, 5, 6, 7, 8]. However, no studies have profusely attempted to understand the post-ricochet behaviour of bullets close to the ricochet impact point. It is also evident that most of the ricochet experiments have attempted to understand the initial conditions of ricochet, and studies on post-ricochet behaviours are rare [9]. The significance of understanding the post-ricochet behaviour of bullets close to the ricochet point was highlighted during a recent experiment [10] that reported on the post-ricochet orientation of the 'main fragment' of AK bullets. The study claims that when AK bullets (lead core bullets) ricochet off of 1 mm sheet metal (between 8 and 20-degree incident angles), the bullets usually fragment and the main ricocheting fragment produces side-on impacts angled to the right on close targets. Although the finding was presented briefly concerning ricocheting bullet fragments, it promisingly highlights the need for further exploration of the reported phenomenon and understanding of any potential forensic significance of close range post ricochet orientation of bullets, when true ricochet occurs from a variety of surface types.

This empirical study aims to explore the close-range post-ricochet orientations of AK bullets (7.62 mm × 39 mm) on a range of target surfaces commonly reported in indoor and outdoor bullet ricochet incidents. 7.62 mm × 39 mm bullets used by AK rifles were selected as the testing bullet type in this study, with eight surface types that are commonly reported in indoor and outdoor bullet ricochet incidents. An AK-type rifle was selected as they are known as the most frequently used weapon type in recent gun crimes [11], and currently, there is an increasing trend in the use of this firearm in crime scene shootings worldwide [12]. Therefore, in addition to filling the existing knowledge gap, the findings of this study concerning the selected bullet type and target surfaces have real-world significance over the other gun types currently reported in crime scene shootings worldwide.

2. Methodology

2.1 Experimental setup

This study used a commonly used experimental setup in many empirical ricochet studies [13-17]. A firmly mounted AK variant rifle fixed on a stable steel platform was used to fire at different target surfaces held at varying angles to the bullet's path. The distance from the gun barrel (muzzle end) to the point of impact on the samples was 10 m. The gun mount was precisely levelled to the ground with a height of 1.4 m from the muzzle end. After every shot, the level was checked using a customised bore-sighting tool with a bubble level. It is acknowledged that fixing the weapon in the horizontal position negates any recoil effects that would be experienced in real-life shootings [18]. However, in the authors' experiences, recoil effects are not significant over a single shot when the weapon is fired semi-automatically.

A steel base held a target tray which supported the samples at different angles for firing. The targets were supported around their edges and so remained unsupported directly underneath the impact sites. The target tray was pivoted to the front end of the steel base with two points enabling it to lift from the other end to set different angles. A calibrated digital inclinometer with a precision of +/- 0.10 degrees was used to set the angles of the target tray [19]. The horizontal levels of the target holding base and the target tray were precisely paralleled to the ground and regularly checked using the digital inclinometer. Once an angle was set, the sample targets were kept on the target tray for firing. It was locked to ensure no changes to the set angles due to the bullet's impact. The impact point of the samples was set at the same height as the muzzle end of the gun, 1.4 m from the ground level. White paper (A3 size) was clipped to hardboards that were placed at the rear edge of the target surfaces as witness screens (fixed perpendicular to the target surface) to capture the orientation of the bullet impacts. A steel frame was firmly fixed on the target tray to hold these paper screens.

10 shots were fired at each angle starting from a 5-degree incident angle (incident angles below 5 degrees could not be tested due to experimental difficulties). The incident angle was increased at 2-degree intervals until the critical angles for each bullet and surface combination were achieved and no more ricochets were observed. The critical angles of the wood surfaces were identified when bullets perforated the samples. For other surface types, the critical angle was identified when the bullet perforated or fragmented on impact, as defined by Haag *et al*. [3].

10 to 15 bullet impact marks were collected on one paper screen by moving the entire target tray from right to left along the steel base without changing the levels. The same procedure was repeated for all target surface types. The velocities of the bullets were measured using a LabRadar chronograph (v.1.3) placed at the side of the muzzle end 30 cm away. A box filled with old telephone directories was also placed behind the target holding frame to capture the ricocheting bullets for analysis. Figure 1 shows the experimental setup with some of the pictures taken. Three angles that characterise the ricochet process are given in Figure 2 to better interpret the angles defined in this study.

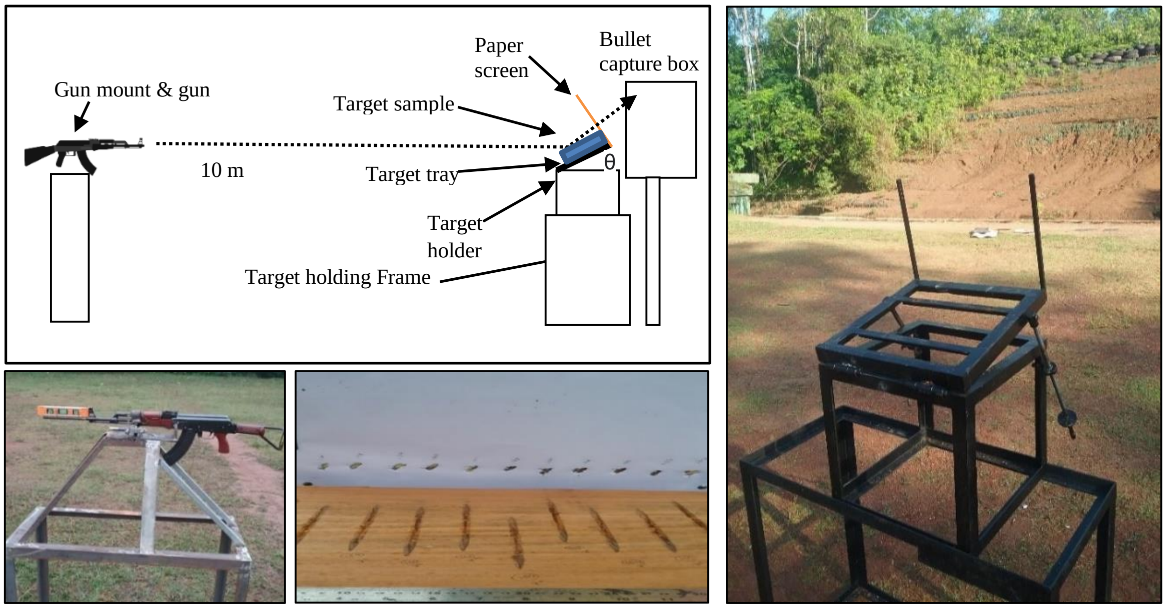

Figure 1: The experimental setup with some of the photographs taken during the experiment.

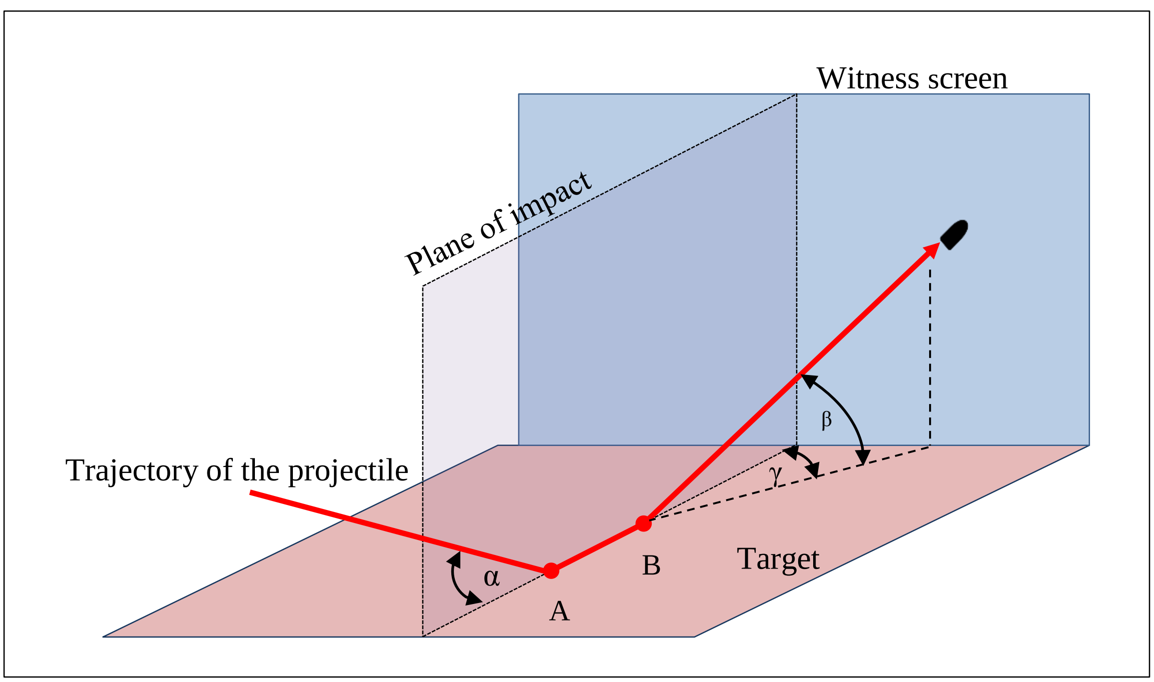

Figure 2: The trajectory of a ricocheting bullet explaining the incident angle (α), the ricochet angle (β) and the deflection angle (γ). A and B relate to the initial point of impact of the projectile and the point the projectile leaves the surface after ricochet, respectively.

The bullet impact marks on the paper screens were used to identify the post-ricochet orientations of the ricocheted bullets. The distances between the ricocheting points to the impact marks on the paper screens were measured. A long-range digital calliper [20] was used to measure the distances and was zeroed before taking all the measurements. The front end of the ricochet mark on the testing surface and the bottom edge of the impact marks on paper screens were used as the reference points for measurement taking. The distance travelled by each ricocheting bullet from the impact points on the target surfaces to the paper screens (from the front edge of the ricochet marks on the wood surface to the bottom edge of the impact marks on paper screens) was calculated using Pythagoras' theorem. The heights of the impact marks from the surfaces and lengths of bullet impact marks were also measured and recorded.

When a bullet indicated a side on impact, where the bearing surface of the bullet mostly impacts the paper screens, the angular component formed between the bullet's impact orientation on the paper screen and the horizontal bottom edge of the paper screen was measured and recorded. To measure the angles, first, the paper screens with bullet impact marks were removed from the mounts, and lines were drawn along the full lengths of each bullet impact mark, dividing it into two equal parts. A transparent plastic ruler was used for this purpose. The drawn lines were then extended downwards until they intercepted the horizontal bottom edge of the paper screens. The angle formed between the line drawn and the horizontal bottom edge of the paper screens was measured using a digital protractor [21].

2.2 Firearm and ammunition

The ammunition used for this experiment was 7.62 mm × 39 mm standard M43 type (boat-tail base) with steel core and copper jackets, produced by Norinco Ammunition Factory, China. The rifle used was a Type 56 (Chinese-made) with a right-hand twist gun barrel.

2.3 Target surfaces

Three flat wood blocks (mahogany, jackwood and teak), glazed ceramic wall and floor tiles, cement blocks, and two concrete samples with different surface compositions and textures were used as target surfaces to examine the post-ricochet orientation of bullets. These target samples were selected to represent some of the main surface categories explained in ricochet-related literature, being yielding, non-yielding and frangible [3]. Their common existence in the urban environments, along with ricochet potential, was considered when selecting target samples. A detailed description of the targets used for the study and how they were prepared is given below.

2.3.1 Yielding Target Surfaces

Three flat wood samples of a 1-inch thickness (mahogany, jackwood, and teak) were selected as yielding surfaces. These were the size of 450 mm × 450 mm × 25 mm. The samples were each selected from one single tree. All wood samples had been finished to have a smooth surface, and no other modifications or improvements such as painting or polishing were made. Grain angles of the wood samples were kept perpendicular to the bullet impacts during the firing. A wood hardness test was performed by a qualified scientist employing the Janka Wood Hardness Test method [22]. Table 1 depicts the reported average hardness values of wood samples along with the hardness order.

Table 1: Results of Janka wood hardness test for the selected wood types.

Wood type	Measured average hardness of the samples (N)	Order based on the hardness
Teak	4544	1
Jackwood	3674	2
Mahogany	3470	3

2.3.2 Frangible Target Surfaces

Glazed ceramic floor and wall tiles were used as a known frangible surface type [3]. Floor tiles were of the size of 400 mm × 400 mm × 8 mm and complied with ISO 13006:2012-E (Annex

J) and BS EN 14411:2012 [24]. Wall tiles were of the size of 300 mm × 450 mm × 5 mm and complied with ISO 13006:2012-E (Annex L) and BS EN 14411:2012 [23]. The measured average breaking strength of the wall tiles was 500 N and 1000 N for the floor tiles. Both tile types were mounted on concrete blocks of the same size as the tiles, on top of a cement (20 mm) and a mortar layer (4 mm) to comply with the general standards of tile-laying [24] to give more realistic bullet impacts for the tiles. The tile samples were used for this study three months after being laid on the concrete base.

2.3.3 Non-Yielding Target Surfaces

Rough concrete surfaces are known as a non-yielding surface type [3]. Concrete blocks of 450 mm × 450 mm × 100 mm were made using the cement (Portland), sand, and gravel mixing to the M15 ordinary grade mixing ratio of 1:2:4 [25, 26]. The mixer was made using a concrete mixing machine and poured into wooden frames sized 450 mm × 450 mm × 100 mm. The surfaces of the samples were levelled using a hand trowel to obtain a smooth finish with no gravel on top. Samples were kept outside to dry for three months before being used for this study. After drying, the natural, roughly finished upper flat surfaces were used as the 'rough' concrete samples.

'Intermediate' concrete surfaces were made to observe the bullet's behaviour with an added layer on the same concrete surface. For that, 2 mm thick skimmed cement layers were applied on top of concrete blocks, prepared according to the same method above. The mixture was poured into the blocks and levelled using a masonry trowel until the smooth and polished cement finish appeared. After one hour, the skimmed cement layer was applied on top of the concrete surfaces. This technique is used to make popular industrial concrete textures during concrete construction [27, 28, 29] and is commonly found on contemporary urban concrete structures as a modern architectural finish.

Cement samples were made by adding a 20 mm cement layer (a mixture of cement (Portland) and sand with an ordinary mixing ratio of 1:4 [30] on top of another set of concrete blocks made with the same method described above. These samples were made to represent ordinary cement plastered walls. All the samples were stored outside and used for the experiment after three months of making them.

2.4 Data analysis

Ricochet angles of bullets were calculated using basic trigonometry, as done in most of the ricochet experiments [13-17].Cumulative Failure Analysis in Minitab software was used to estimate the critical angles as done in the previous ricochet studies highlighted.

The measured post-ricochet angles are referred to as 'post-ricochet yaw angles' herein forth. A pictorial explanation of the measuring of the post-ricochet yaw-angle and length of a bullet impact is illustrated in Figure 3.

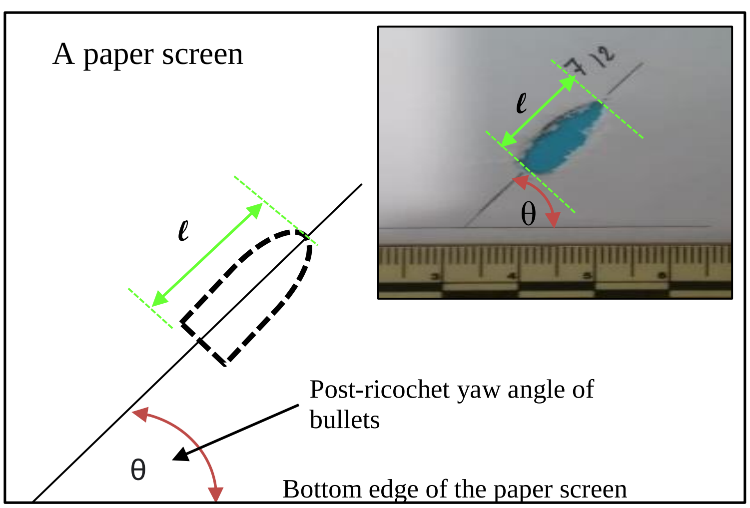

Figure 3. The measuring of the post-ricochet yaw angle of bullets (θ) and the length of the bullet impact marks (**ℓ**). A blue-coloured paper was placed behind the paper screens to highlight the impact mark better when photographs were taken.

A one-way ANOVA was performed using the IBM SPSS statistics tool (31) to conduct the statistical analysis. Partial Eta squared method was employed to measure the effect size of different variables; small effect = 0.01, medium effect = 0.06 large effect = 0.14 [32]. The "effect size is a quantitative measure of the magnitude of the experimental effect. The larger the effect size indicates a stronger relationship between two variables" [33]. The Partial Eta squared method is used in ANOVA models and these effect sizes represent the amount of variance explained by each of the model's terms, where each term can be represented by 1 or more parameters [34].

3. Results and Discussion

The average velocity of the bullets fired in this study was 712 ± 20 m/s. No lateral deviation of the ricocheted bullets was observed due to the close range from the ricocheting points to the paper screens. The average measured distance of the post-ricochet trajectories from the ricochet marks to the impact marks on paper screens was 167 ± 30 mm. The post-ricochet orientation of AK bullets observed with each surface type is presented and discussed separately in the following sections.

3.1 Post-Ricochet Yaw Angles of Bullets with Wood Surfaces

Estimations of the critical angles for the bullets on the wooden surfaces were calculated using Cumulative Failure Plots and were found to be 13, 9.9 and 12.7 degrees respectively for teak, jackwood and mahogany. As per the measured wood hardness in Table 1, the critical angle of jackwood should be greater than the critical angle of mahogany to support the existing understanding, where critical angles increase with the wood hardness [35, 36]. However, the critical angle reported with jackwood did not support this theory and the resulted phenomena could have occurred due to a combined effect of the bullet's shape, velocity and most significantly, the variations of wood properties and unique surface reactions to ricocheting bullets. Surface reaction to the ricocheting bullets has been highlighted as a significant factor in recent ricochet experiments. These studies have demonstrated how significantly the ricochet behaviours of bullets can change due to slightest surface variations [14] and different orientations of the target surface (i.e orientation of the wood grain structure) to the bullet's impact [37].

Ricocheted bullets off three wood types all demonstrated side-on impacts with the paper screens with a rightwards yaw. Evidence suggests that the bullets had undergone an approximately 90-degree upwards rotation upon impacting the paper screens. No significant damage or deformation to the recovered bullets was observed. Long symmetrical creases had been produced on each wood surface. The lengths of the creases tended to decrease as the angle of incidence increased. In contrast, the depth of the creases was observed to increase with an increased angle of incidence. Some photographs from the bullet impact marks on the paper witness screens are shown in Figure 4. Figure 5 illustrates the nature of the creases produced by ricocheting bullets on different wood types. Figure 6 summarises the average post-ricochet angles reported for three wood types and the corresponding angle of incidences.

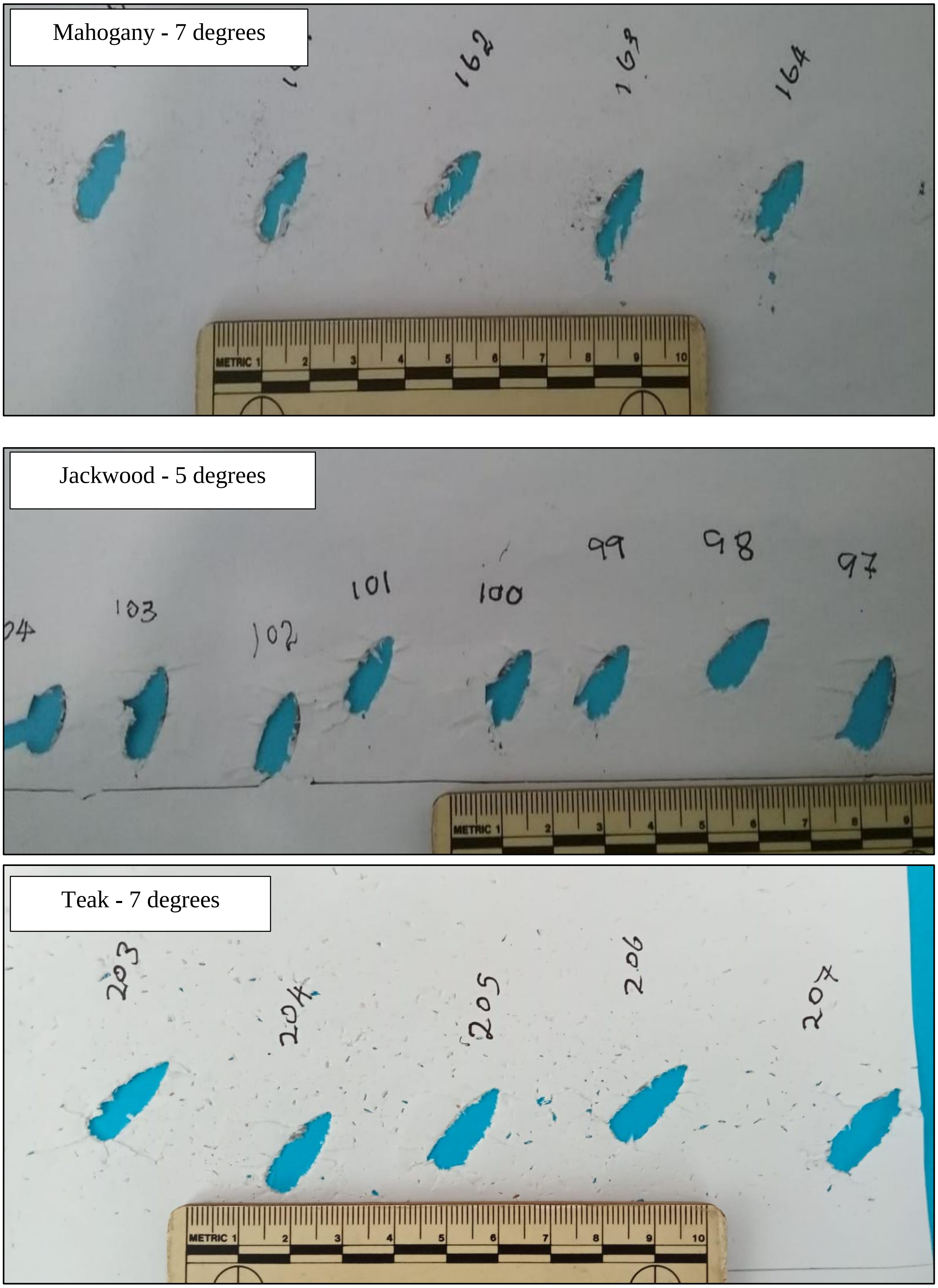

Figure 4: Photographs of the bullet impact marks on the paper witness screens after ricochet off some of the wood samples.

Figure 5: Creases produced with some of the wood samples

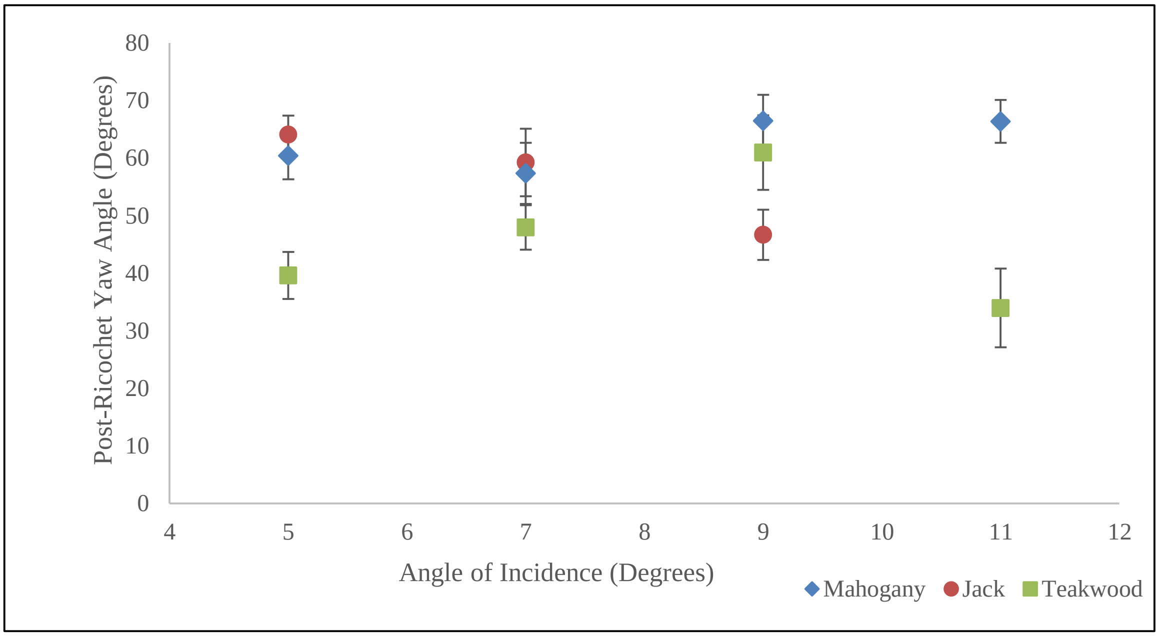

Figure 6: Mean post-ricochet angle values and standard deviations reported for three wood types and the corresponding angles of incidence.

Post-ricochet yaw angles reported with each wood surface were found to be between 25 and 72 degrees with a variation in the results between different wood types. The measured lengths of the bullet impact mark on the paper screens (Figure 3 - referred to as ℓ) were similar to the original length of an AK projectile (23 mm), with ± 3 mm difference. These impact marks demonstrated side on impacts of the bullets almost parallel to the paper screen. The ricochet angles reported complied with the existing literature; whereby ricochet angles were greater than angles of incidence [3], and no relationship was observed with the post-ricochet angles of the bullets.

A one-way ANOVA performed for each incident angle revealed that there is a statistically significant difference in mean post-ricochet angles between at least two groups (5 degrees = ($F(2, 27) = [105.529]$, $p =< 0.001$), 7 degrees = ($F(2, 27) = [12.981]$, $p =< 0.001$), 9 degrees = ($F (1, 18) = [151.934]$, $p =< 0.001$), 11 degrees = ($F(1, 18) = [105.934]$, $p =< 0.001$). The resulting F values and corresponding p values indicate that the means of the groups are significantly different, and the results are statistically significant. Eta squared tests for each angle of incidence indicated large effect sizes between mean differences of post-ricochet angle groups (5-degrees = 0.887, 7 degrees= 0.490, 9 degrees = 0.730 and 11 degrees = 0.894. The results indicate variability of post-ricochet yaw angles in relation to the angle of incidences and wood type. Mean differences of post-ricochet yaw angles reported with each angle of incidence for three wood groups are graphically illustrated in Figure 7.

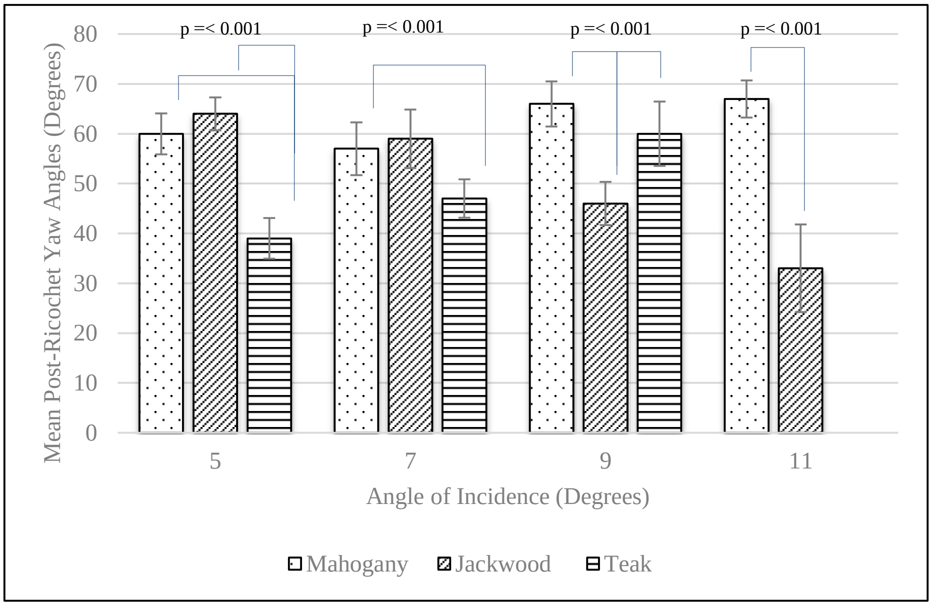

Figure 7: Mean post-ricochet yaw angles and standard deviations reported for the angles of incidence used on wooden impact samples.

The orientation change of the bullets soon after the ricochet points, as evident from the impact marks on paper screens, are believed to have occurred due to the instant axis change during the ricochet process and the rightwards spin of the bullets imparted by the barrel rifling. Because of the projectile-target interaction, the symmetry axis of the projectile changed (characterised by the ricochet angle (β) and both the velocity and the projectile spin decreased. The latter is likely to affect the dynamic stability of the projectile, resulting in the angle to the right impacts observed on the paper screens. The yaw angles reported here come from the angle relative to the horizontal axis on the paper witness screens but can be interpreted as the approximate rotation relative to the symmetry axis of the projectile and its pre-impact velocity vector. Any possible effect of gravity, air resistance and drag cannot be assumed to be responsible for the observed behaviour, as resistance from such forces are believed to be negligible due to the extreme short post-ricochet trajectories being analysed in this study.

To provide more empirical evidence for the above-explained phenomenon, a screen holder with five parallel paper witness screens (with 36 mm spacing) was fixed behind the impact points of several wood samples. Shots were fired at different incident angles to understand the change in yaw angle of the ricocheting bullets when they pass through the screens (this was done as an alternative to the use of a high-speed camera, which was not available). The bullets' post-impact behaviour was observed by the impact marks left on the individual screens and their post ricochet yaw angles were measured. The evidence further supported the previous observation that the bullets instantly yaw to the right upon impact. The average rightward yaw angles of the bullets from the first to the fifth screens was generally seen to increase. For example, a bullet fired at 9 degrees to a Mahogany sample showed a rightwards yaw angle of 47 degrees from the horizontal axis on the first screen and 25 degrees on the last screen, highlighting a 22-degree change in the rightwards yaw over a distance of 144 mm. The experimental arrangement, the post-ricochet yaw angles measured from the respective screens at 9 degrees with the Mahogany sample and a schematic explaining the behaviour of post-ricocheting bullets identified when viewed from the firing point are illustrated in Figure 8.

A similar phenomenon has been reported in a previous ricochet study considering the ricocheting 'main' fragments of AK bullets [10]. It was shown that ricocheting AK lead core bullets off 1 mm sheet metal fragmented upon impact from 5-degree incident angles upwards, and the ricocheting main fragment had maintained a rightward yaw orientation close to the point of ricochet. The previous study's results compared well with the rightwards yaw rotation for the side on impacts reported in this current study with M43 steel core bullets, suggesting that the reported behaviour of the AK bullets is an impact-induced effect common to ricochet events.

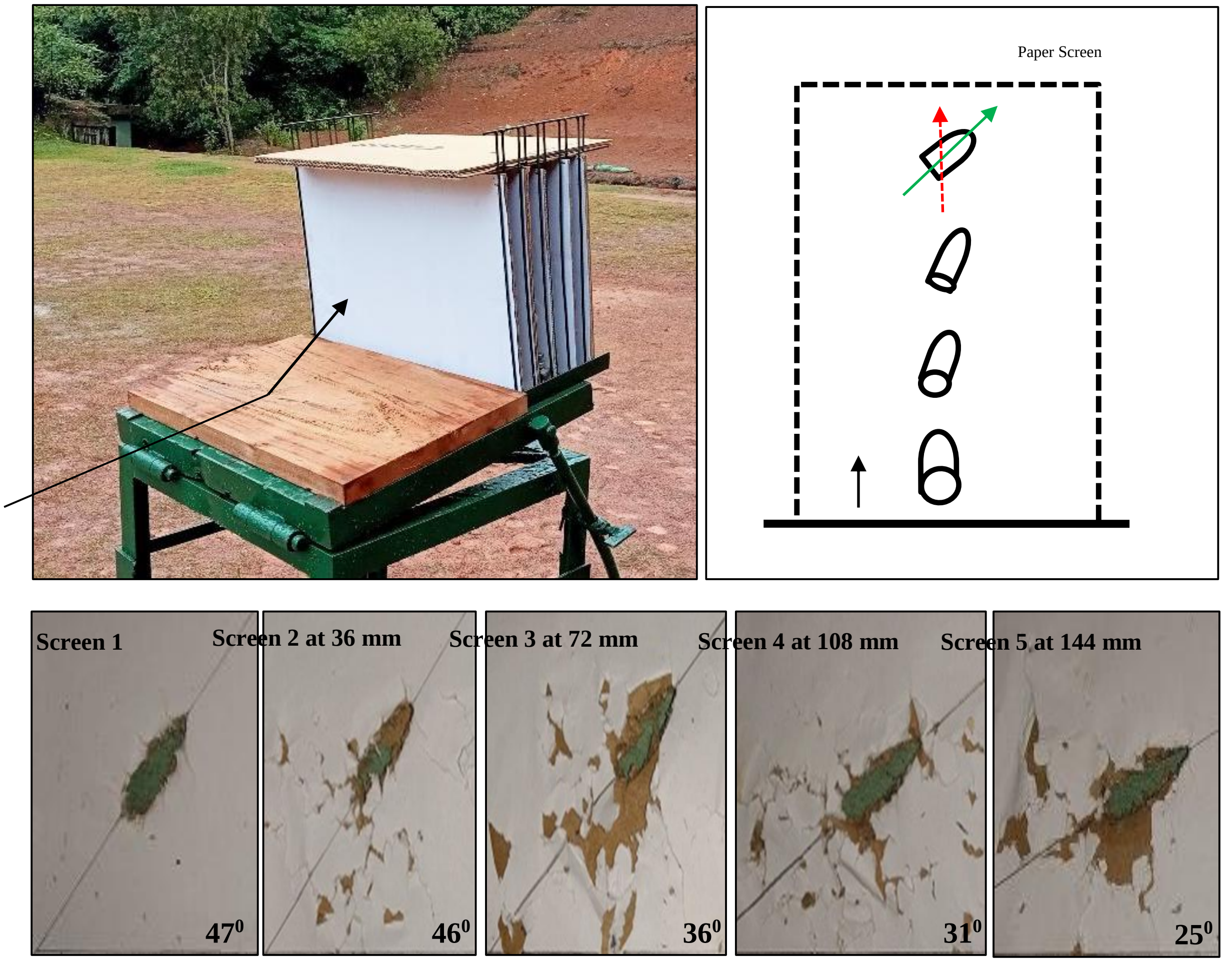

Figure 8: Experimental setup to observe the post-ricochet change in yaw by distance travelled. The Schematic at the top right indicates the AK bullet's change of axis, leading to an approximate 90-degree rotation and adopting the rightwards yaw orientation soon after the ricochet. The green arrow indicates the rightwards post-ricochet yaw angle of the bullet, as viewed from the shooter's direction. The red arrow indicates the original orientation of the bullet when it first impacted the surface, and the black arrows indicate the direction of the bullet.

When bullets ricochet off wood surfaces, the wood surfaces usually yield to the bullet's advance; therefore, creases are usually produced [13]. Although wood is considered to be a yielding surface, the surfaces impart a considerable resistive force to the ricocheting bullets, especially when they move on the surfaces producing long craters at low incident angles. The resistance and frictional forces experienced by the bullets also increase when the angle of incidence increases, with a greater component of the bullet's force pushing into the wood's surface, permitting the bullet to penetrate deeper and interact with a greater surface area of the wood. The increased resistance with the increasing crease depths could explain the changing trend and increased standard deviations in Figure 6, around 7 to 9 degrees. The increased standard deviations reported at higher angles with jackwood (3.3 degrees at the 5-degree incident angle and 8.8 degrees at the 11-degree incident angle) and teak (4.1 degrees at the 5-degree incident angle and 6.8 degrees at the 11-degree incident angle) clearly support this explanation. Moreover, the standard deviations reported with each wood type for different incident angles can also be indicative of the changing resistance of wood surfaces to the bullets across the wood surfaces. Across the surface, the wood anatomy, structure and therefore, physical properties will vary depending on whether the area has pitch, hardwood, annual rings or sapwood, each with slightly different hardness levels [38]. The variations seen could be due to these slight structural variations and the change of resistance experienced by the bullets when they move on the wood samples. This can be further explained by standard deviations reported for the Mahogany samples at 11 degrees. Mahogany samples used for this experiment had the lowest hardness value of the wood types used (Table 1). These samples were visually observed to have a plain and homogenous structure with less anatomical variations than the other wood samples. Therefore, the reduced anatomical variation could correlate with the comparatively low standard deviations reported with Mahogany samples at higher angles of incidence. The observations also suggest that the wood hardness and the anatomical variations strongly correlate to the variations in the post-ricochet bullet's rightwards yaw angle at close distances. Effects of yaw, nutation and precession of the bullets when they impact the targets [39] can also be assumed to contribute to the variations; however, no data was collected to establish this claim. Ricochet angles reported with all wood types were in line with the existing literature; with ricochet angles exceeding the angles of incidence [3]. No relationship was found between the ricochet angles or critical angles and the post-impact orientation of the bullets.

3.2 *Post Ricochet Orientation of Bullets off Floor Tiles*

Similar to the wood samples, the rightwards post-ricochet yaw of bullets and side-on impacts on the paper screens were observed with wall tile samples. The post-ricochet yaw angles reported with floor tiles were limited to 5 and 7 degrees as the critical angle was achieved early, at around 9 degrees (9.99 degrees). Post-ricochet yaw angles reported were range from 34 to 51 degrees and the average values of 38 and 55 degrees were seen for the 5 and 7-degree angles of incidence, respectively. No surface cratering was observed with floor tiles, although slight scratching effects were observed without further developing into a 3-dimensional crease. The post-ricochet yaw angle reported for the floor tiles was observed to be close to the angle range reported with wood sample types (25 to 72 degrees). The collected bullets had been flattened on the side that had impacted the tiles. The degree of deformation seemed to increase when the angle of incidence increased from 5 to 7 degrees; however, the bullet's core and jacket remained intact. A photograph of some of the impacts on the tiles is shown in Figure 9.

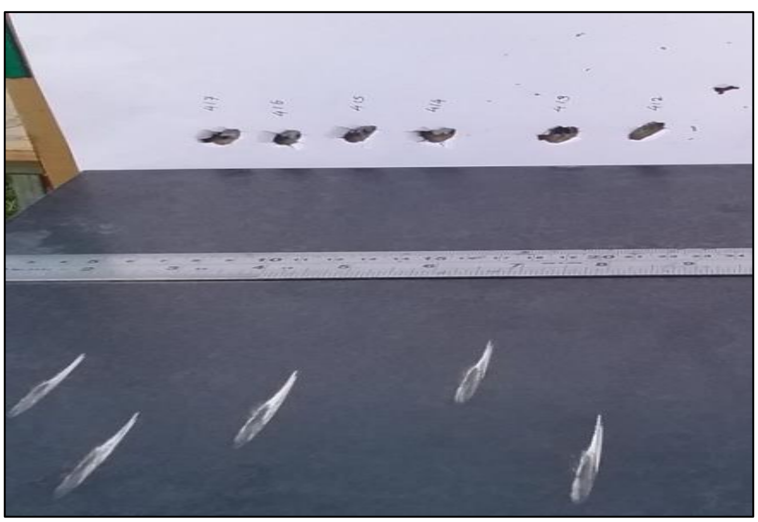

Figure 9: A photo showing some of the bullet impact marks upon the floor tiles along with the corresponding paper witness paper.

When bullets impact frangible surfaces such as tiles at low incident angles, the surfaces initially behave as if un-yielding to each bullet impact [3]. The increased surface resistance compared to the wooden substrates means that less energy is transferred into damaging the sub-surface during this phase and the bullets therefore skid over the surface with no craters. The interaction time of the bullet with the surface is also therefore shorter compared to the wooden surfaces, due to this skidding action. When the incident angle is further increased, either the bullet fragments upon reaching the critical angle (if the bullet is softer than the surface) or it will ricochet off with a brittle shattering of the sub-surface [3]. The un-yielding phase, as explained above, was observed with floor tiles at 5 and 7 degrees and the bullets fragmented, at 9 degrees, suggesting they have reached their critical angle. The bullets retrieved from the soft capture box had been flattened on one side with differing degrees of deformation depending upon the incident angle. This indicated a significant interaction with the surface and notable energy expenditure in deforming the projectiles from the process. Measured lengths of the bullet impact marks also indicated side on impacts with bullets being parallel to the paper screens. However, more variation (± 6 mm) was reported than for various wood types (± 3 mm), possibly due to the bullet's deformation and shape change after the impact with floor tiles.

Unlike with the wood surface, ricocheting bullets off floor tile surfaces will not have experienced varying resistive forces during ricochet due to the hard and homogeneous tile surface and no surface cratering. This resulted in low associated standard deviations (0.7 to 1.8 degrees). Ricochet angles reported were in line with the existing literature; with ricochet angles being less than angles of incidence [3]. No relationship was found between the ricochet angles or critical angles and the post-impact orientation of the bullets.

3.3 Post Ricochet Orientation of Bullets off Wall Tiles

The post-ricochet yaw angles reported with wall tiles were limited to 5, 7, and 9-degree incident angles, as the expelling debris has damaged the paper screens to mask the bullet impacts at higher angles. However, the critical angle of bullets was estimated to be 15.97 degrees where bullets fragmented on impact, based on the Cumulative Failure Analysis. The reported post-ricochet angles were between 33 and 147 degrees, reporting a comparatively higher range than the wood and wall tiles. Significant variations of the post ricochet yaw angle for the bullets were also observed, although they were consistently pointing to the right once again. The length of the impact marks produced on the paper screens with wall tiles differed considerably between each shot, demonstrating a greater variability of impact orientations of the bullets. However, in general, the rightwards post-ricochet yaw was maintained throughout.

In contrast to the lack of creases produced on the floor tiles, craters were produced on all the wall tile samples. These craters were irregular and asymmetrical in shape. The degree of cratering was observed to increase as the angles of incidence increased, as did the degree of deformation to the bullets. Figure 10 highlights the key results along with a photograph of the bullet impact marks on the paper witness screen and the craters produced on a wall tile sample.

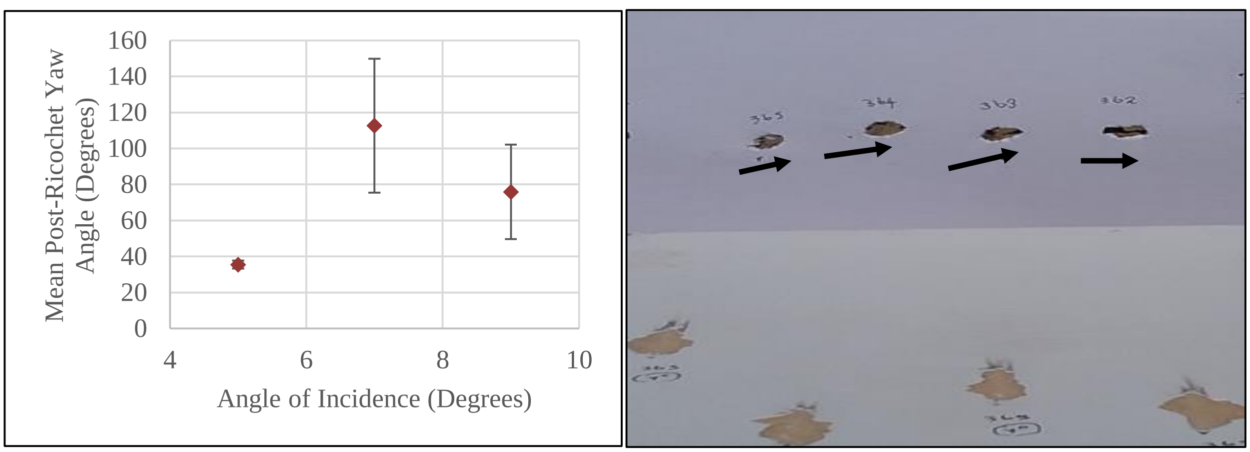

Figure 10: Mean post-ricochet angles and standard deviations of wall tiles and a photograph of the bullet impact marks on the paper witness screens at 7 degrees.

The standard deviations of post-ricochet yaw angles reported were high compared to wood and floor tile surfaces. The standard deviation reported at a 5-degree incident angle is less (2.2 degrees) with minimal surface cratering compared to higher values reported with other angles (37.2 and 26.2 degrees for the 7 and 9-degree angled of incidence). This is due to the comparatively less interaction time of the bullets with the surface in lower angles than in higher angles. Unlike with floor tiles, from 5 degrees upward, the failure point of the wall tiles was achieved at all incident angles due to the relatively lower hardness than for the floor tiles. As a result, irregular craters were produced when the bullets ricocheted off the homogeneous target material due to a frangible material failure mechanism in action [3]. In such instances, the bullet impact shatters the surface structure, extending deepest at the point immediately below the point of initial contact. The continuously advancing and ricocheting bullets then flake away more material toward the departure side of the crater [3]. The irregular surface cratering subsequently effects the spinning bullet's post-ricochet orientation, which is believed to have caused the high associated standard deviations at 7 and 9-degree angles of incidence.

These observations along with the findings of wood and floor tile surfaces suggest that the nature of the failure mechanism of the surface type during the bullet-target interaction in a ricochet process has a direct bearing on the consistency of the post-ricochet orientation of AK bullets. A strong statistical significance was observed between the post-ricochet angles and the two tile sample types at 5 and 7 degrees (5 degrees = (F (1, 18) = [377.24], p =< 0.001), 7 degrees = (F(1, 18) = [39.8], p =< 0.001). Eta squared tests for each angle of incidence indicated large effect sizes between mean differences of the two incident angle groups (5 degrees = 0.954, 7 degrees= 0.83). (Standard range- small effect = 0.01, medium effect = 0.06 large effect = 0.14) [33].

3.4 Post Ricochet Orientation of Bullets off Concrete and Cement Samples

The bullet impact marks on the paper witness screens for concrete and the two cement samples were typically circular for the 5-degree angle of incidence, indicating nose forward impacts with the paper screens (Figure 11). Above this angle, no clear bullet impacts were observed on the paper screens, as the ejected debris from the surfaces had followed the bullets and created sufficient damage to mask any bullet holes. However, true ricochets were evident given that deformed bullets were found in the bullet capture box. Critical angles observed for the surfaces were 10.8, 11.1 and

13.2 degrees for rough concrete samples, intermediate concrete samples and cement samples, respectively. No craters were produced on concrete due to the hard and unyielding nature of the samples and complied with the current understanding of the ricochet behaviour of bullets off unyielding surfaces [3]. Craters were produced on the intermediate, and cement surfaces, complying with typical frangible surface reactions explained in the existing literature [3, 14].

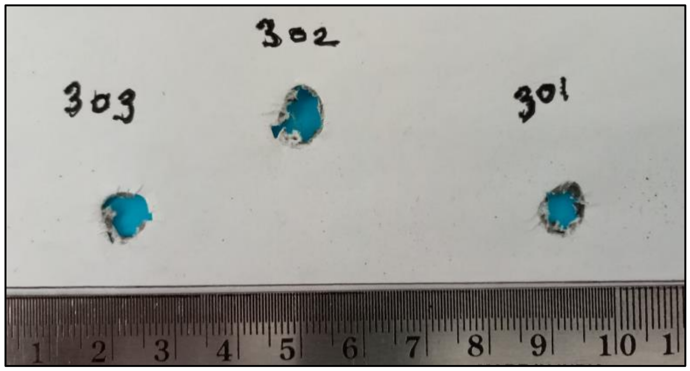

Figure 11: Circular bullet impact marks observed from post-ricocheting bullets with an intermediate concrete sample at a 5-degree incident angle.

Low interaction times for the bullet on the surface at the 5-degree incident angle and low frictional forces resulted in minimal interference with the ricocheting bullets' post-impact orientation. It is also significant to notice that the same circular bullet holes had been reported in a previous study [10] at 3 degrees, when the main fragment of the AK bullets ricochet off 1 mm sheet metal. The results of this study compared to previous observations demonstrate the variability in the nose-forward orientation of ricocheting bullets at low incident angles in relation to the surface type. This particular finding is important for shooting reconstruction professionals given that bullet entry wounds on a human body from such nose forward impacts could be misinterpreted as a directly fired shot if the scene is not fully analysed.

The existing literature elaborates on many bullet ricochet incidents similar to the experimental setup of this study in which nearby ricocheted bullets killed or injured victims [4, 5, 6, 7, 8]. The post-ricochet yaw angles reported particularly with wood and floor tile surfaces in this study bear real forensic value for scene reconstruction of such future incidents. To further assess this, five porcine skin samples with some underlying flesh still attached of size of 450 mm × 450 mm were fixed onto the witness screen holder. These were approximately 50 mm thick in total consisting of approximately 25 mm of skin and 25 mm of flesh. 5 x test shots were fired into wood and floor tile samples at 7 and 9 degrees. Entry wounds from the ricocheted bullets on porcine samples indicated the same angle to the right yaw in relation to the ricochet surface and side on impacts similar to the impact marks observed on the paper screens. The elongated entry wounds clearly featured the bullet's shape (Figure 12). The observations highlighted that these findings can be used to suggest the approximate body position or the position of a body part when a close range ricocheted bullet impacts human soft tissue. However, the approximate incident angle of the bullet should be established prior and the distance from the victim to the ricochet points must be similar to the experimental setup of this study. Two hypothetical situations in which the findings can be used are illustrated in Figure 13.

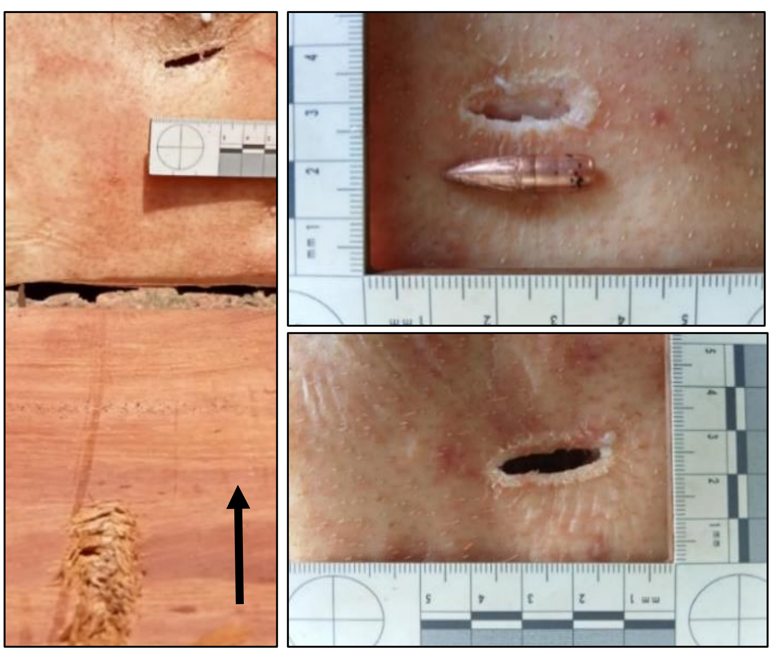

Figure 12: Post-ricocheting bullet impacts on porcine skin samples (wood surfaces). These impacts were angled to the right, similar to the impact marks on paper screens, and the bullet's orientation on the skin was clearly identifiable.

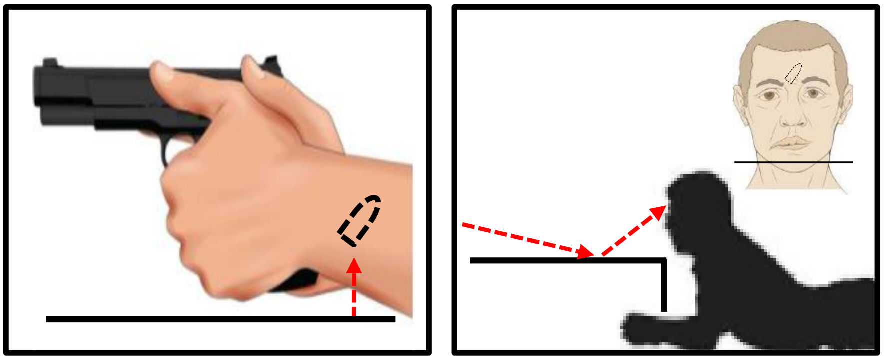

Figure 13: The picture on the left illustrates a hypothetical example of someone being shot in the hand while aiming a gun, being hit by a ricocheting bullet from a wooden surface and the approximate incident angle is known. The picture on the right illustrates a ricocheting bullet impacting a head while the individual is in the prone position. On both occasions, the elongated wound features and their rightwards orientation on the victim's body can be used to reconstruct the approximate orientation of the hand/ head at the time the ricocheting bullet impacted the victim.

To test whether the observed post-impact yaw of bullets is observable when bullets impact wood and tile surfaces at non-azimuth angles, the target frame and the target holder itself were modified. Two L-angle bars were welded to the target frame (as shown in Figure 14) with a 25 mm gap. A steel rod was attached to the bottom of the target tray assembly and was inserted between the bars, with a roller bearing was fixed at the end of the rod. With this modification, the target tray could be rotated 360 degrees on the steel structure while moving along the L angle bars. A paper screen holder was also fitted at the back of the tray, perpendicular to the gun barrel's axis. After the modification, the target samples could be placed in different orientations to the bullet impacts to see the post-ricochet yaw of bullets at non-azimuth angles. After the changes, wood and tile samples were inserted on the target tray and one test shot was fired at 45 and 20 degrees changing the incline angle from 7 degrees until the critical angles were reached. Afterwards, the tray was rotated 90 degrees, and the same sequence was repeated. Rotation of the target tray and repetition of the sequence was done mainly to see if the bullet's spin and post-ricochet yaw were affected by the grain orientation. A picture of the modified target holder with a Mahogany wood sample placed at 45 degrees with a 9-degree incline is given in Figure 14. An explanation of how the samples were placed is also illustrated.

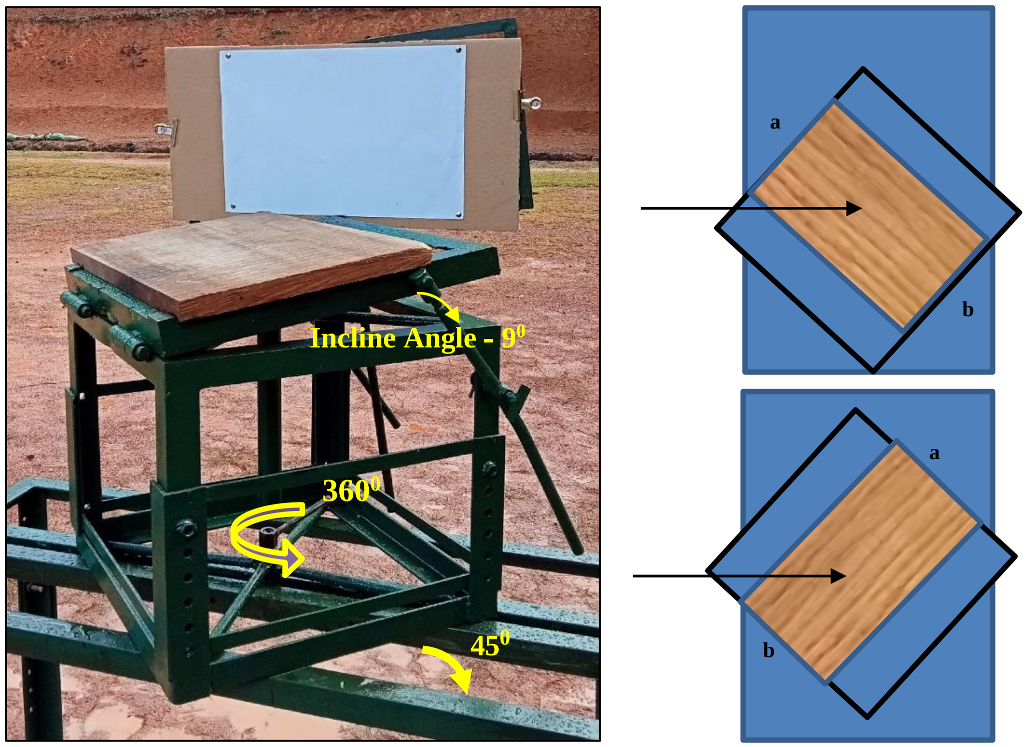

Figure 14: A picture of the modified target holder with a Mahogany wood sample placed 45 degrees to the bullet's impact with a 9-degree incline (left) and how the target tray was rotated (right).

The bullet impacts on the paper screens demonstrated the same general rightwards yaw with both wood and tile samples. Lateral bullet deflection to the right as a result of the rightwards spin of the projectiles were also expected and have been described in the existing literature [3]. However, this was not observed in this study, with the bullet trajectory (rifle barrel), impact mark and the silhouette of the ricocheting bullets on the screens always being aligned (Figure 2), regardless of different non-azimuth orientations. The short distance from the impact point to the paper screen could be the reason for this. Post-impact yaw values reported with different wood types at non-azimuth angles (16 x different non-azimuth angles for Mahogany and Teak and 12 non-azimuth angles for Jack wood), were all within the previously reported range (25 to 70 degrees) with azimuth angles. Only minor variations within each wood type and incident angle combination were observed and are likely due to the differences in wood anatomy and orientation as the different non-azimuth angles were explored.

Post-ricochet yaw of bullets reported with the floor tile samples displayed more consistency with the related azimuth results. The average post-ricochet yaw angles reported with floor tile samples for 8 different non-azimuth angles ranged between 32 and 57 degrees, which is close to the range for the average values reported for the equivalent azimuth experiments at 5-degree (38 degrees) and 7-degree (55 degrees) incident angles respectively. The higher consistency of the results for the floor tiles when compared to the other sample tested suggests that they may possess a more significant reconstructive value due to the way their non-yielding characteristics lead to no surface cratering. Surface damage has been shown here to affect the consistency of post-impact data. It suggests that when bullets ricochet off floor tiles, a close range located target's orientation (as highlighted in Figure 13) could be estimated with approximate ± 15 degree accuracy, based on the orientation of the bullet impact mark on the target. The resulting post-ricochet yaw values of the wall tile sample were similar to the results in azimuth angles, where values were highly inconsistent. They ranged from 20 to 150 degrees. A picture highlighting the post ricochet angle of bullets fired into a Mahogany sample at a non-azimuth angle (placed at 45 degrees to the bullet's impact and 7 degrees incline angle is given in Figure 15.

Figure 15: Post impact yaw of bullets when bullets ricochet off a mahogany sample placed at 45 degrees to the bullet's impact and 7 degrees incline angle.

4. Conclusion

The close-range post-ricochet orientations of AK bullets were examined in this study with different target surface types. A paper screen was fixed at the far end of the target samples and the impacts of the ricocheting bullets and their orientations were captured and analysed. Ricocheted bullets off wood and tile samples indicated side on impacts for the ricocheting bullets on the paper screens, after having undergone approximately 90-degree rotations from the bullet's initial axis. The measured yaw angles of the bullets on the paper witness screens indicate a consistent rightwards yaw of the ricocheting bullets at approximately 167 ± 30 mm away from the ricochet impact points.

Relatively consistent post-ricochet yaw angles were reported with the wooden samples (in the range of 25 to 72 degrees) and for the floor tile samples (34 to 51 degrees). Small variations in post-ricochet angles and standard deviations reported for each wood type across incident angles were due to the natural inter- and intra-sample variations that exist between these. Each wood sample therefore presented a different resistance to the bullet impacts across the wood surfaces leading to small variations in both the cratering upon impact and the resultant data. For the bullets ricocheting off the floor tiles, the hard and homogeneous nature of the surface meant that no surface cratering was observed, resulting in highly consistent results. Conversely, while the ricocheted bullets off wall tiles displayed the same rightwards post-impact yawing at impact with the paper screens, the measured post-ricochet yaw angles were not consistent and reported a higher range of 33 to 147 degrees, compared to wood and floor tile samples. The irregular surface cratering resulting from the frangible material failure mechanism associated with the bullet-target interactions is believed to be responsible for this inconsistency. Calculations conducted for each angle of incidence indicated statistically large effects and confirming the variability of post-ricochet yaw angles for the wall tiles in relation to the angles of incidence and surface types.

Due to expelling debris, the same effect could not be verified with cement and concrete samples, except for at the 5-degree angle of incidence. However, and interestingly, the post-ricocheting bullets at 5-degree impacts with concrete and cement samples displayed circular bullet holes indicating nose forward impacts with the paper witness screens. This observation, along with the results of the previous bullet ricochet study, demonstrates the variability of post-ricochet bullet yaw in relation to the surface type impacted. This finding should also be considered during forensic shooting reconstruction efforts to avoid the possibility of misinterpreting wound evidence as a direct impact to a victim's body.

It has been emphasised in the existing literature that the post-ricochet trajectories of bullets are generally impossible to predict in any detail [1], and bullets invariably lose their gyroscopic stability and tumble after ricocheting [40]. However, this study reports evidence that certain post-ricochet details can be predicted with high levels of certainty, such as the reported rightwards orientation of AK bullets (at an average distance of 167 ± 30 mm from the surface impact). The results reported in this work also compare well with a previous ricochet study [10], suggesting that the displayed rightwards post-ricochet orientation of AK bullets is a common behaviour of M43 AK projectiles when ricocheting off many different surface types (except when bullets ricochet at very low angles of incidence, i.e., 3 to 5 degrees).

The observed rightwards projectile yaw is believed to be strongly associated with the right hand spin imparted from the rifling inside of the barrel of AK-type rifles'. Variations reported in the standard deviations of the post-ricochet angles also reflected the different properties of the impact surface materials and how each surface type reacts to the ricocheting bullets. When the ricocheting surface is more homogeneous or unyielding, the post-impact yaw values seemed to be more consistent with surfaces that underwent more significant and irregular surface damage resulting in more varying results.

The relative consistency of post-ricochet yaw behaviour of bullets off the wooden and floor tile surfaces suggests these to be phenomena of great forensic value and should aid future scene reconstructions of ricochet events where similar material and projectiles are involved. Testing with non-azimuth angles also highlights that the same post-impact rightwards yaw is observable when bullets are fired at both azimuth and non-azimuth angles. The results from the floor tiles showed most promise for the prediction of events in real life settings, suggesting that when M43 bullets ricochet off floor tiles, a close range target's orientation could be estimated with approximate ± 15 degree accuracy, using the orientation of the bullet impact mark on the target. In general, it is expected that ricochets that do not lead to significant cratering or other surface damage will tend to produce more reproducible outcomes, which by association will lead to more accurate reconstructions. However, post-ricochet angles should be tested with other non-yielding surface types to properly establish this claim. Further extensions to this study could explore whether the reported phenomenon is specific to M43 type AK bullets or whether this is a more common effect for other bullet types and ricochet surface types. This would help further understand how the post-ricochet behaviour of bullets varies under different conditions.

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